US009267381B2

(12) United States Patent
Morris et al.

(10) Patent No.: US 9,267,381 B2
(45) Date of Patent: Feb. 23, 2016

(54) **COOLED TURBINE AIRFOIL STRUCTURES**

(71) Applicant: **HONEYWELL INTERNATIONAL INC.**, Morristown, NJ (US)

(72) Inventors: **Mark C. Morris**, Phoenix, AZ (US); **Jon Kettinger**, Litchfield Park, AZ (US); **Deane Krmpotich**, Tempe, AZ (US); **Stuart Andrew Harman**, Sun City, AZ (US); **Malak Fouad Malak**, Tempe, AZ (US)

(73) Assignee: **HONEYWELL INTERNATIONAL INC.**, Morris Plains, NJ (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 742 days.

(21) Appl. No.: **13/631,126**

(22) Filed: **Sep. 28, 2012**

(65) **Prior Publication Data**

US 2014/0093389 A1 Apr. 3, 2014

(51) **Int. Cl.**
F01D 5/18 (2006.01)

(52) **U.S. Cl.**
CPC ***F01D 5/183*** (2013.01); ***F01D 5/18*** (2013.01); ***F01D 5/187*** (2013.01); *F05D 2260/201* (2013.01); *F05D 2260/234* (2013.01); *Y02T 50/676* (2013.01)

(58) **Field of Classification Search**
CPC F01D 5/18; F01D 5/181; F01D 5/182; F01D 5/183; F01D 5/184; F01D 5/185; F01D 5/186; F01D 5/187; F01D 5/188; F01D 5/189
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,738,588 A *	4/1988	Field	....	416/97 R
5,382,133 A *	1/1995	Moore et al.	....	415/115
5,511,937 A *	4/1996	Papageorgiou	....	415/115
5,738,493 A *	4/1998	Lee et al.	....	416/97 R
5,779,437 A *	7/1998	Abdel-Messeh et al.	.....	415/115
5,813,836 A	9/1998	Starkweather		
5,820,337 A	10/1998	Jackson et al.		
6,582,194 B1	6/2003	Birkner et al.		
6,808,367 B1	10/2004	Liang		

(Continued)

FOREIGN PATENT DOCUMENTS

DE	102007055410 A1	5/2008
EP	1091091 A2	4/2001

(Continued)

OTHER PUBLICATIONS

EP Examination Report for EP 13 176 906.9-1610 dated Apr. 27, 2015.

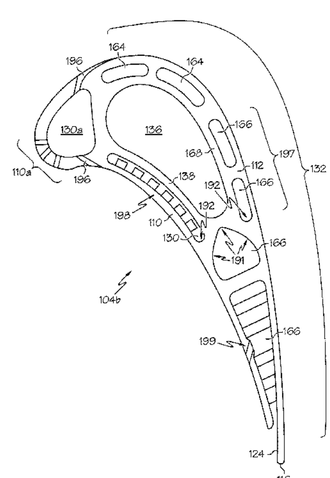
(Continued)

Primary Examiner — Nathaniel Wiehe
Assistant Examiner — Eldon Brockman
(74) *Attorney, Agent, or Firm* — Ingrassia Fisher & Lorenz, P.C.

(57) **ABSTRACT**

In accordance with an exemplary embodiment, disclosed is an air-cooled turbine blade having an airfoil shape, including a convex suction side wall, a concave pressure side wall, the walls including an interior surface that defines an interior with the blade, a suction side flow circuit formed within the blade interior, a pressure side flow circuit formed within the blade interior; and a trailing edge pin bank positioned aft of the suction side and pressure side flow circuits. The turbine blade includes a wishbone-shaped architecture at a transition point between the suction side flow circuit and the pressure side flow circuit and the trailing edge pin bank.

5 Claims, 7 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

6,837,683	B2	1/2005	Dailey	
6,851,924	B2 *	2/2005	Mazzola et al.	415/115
6,974,308	B2	12/2005	Halfmann et al.	
7,008,186	B2	3/2006	Heeg et al.	
7,195,458	B2	3/2007	Liang	
7,217,092	B2	5/2007	Lee et al.	
7,232,290	B2	6/2007	Draper et al.	
7,303,376	B2	12/2007	Liang	
7,371,046	B2	5/2008	Lee et al.	
7,488,156	B2	2/2009	Liang	
7,575,414	B2	8/2009	Lee	
7,625,178	B2	12/2009	Morris et al.	
7,967,566	B2	6/2011	Liang	
7,985,049	B1 *	7/2011	Liang	416/97 R
8,052,389	B2	11/2011	Kopmels	
8,182,223	B2	5/2012	Pal et al.	
2007/0128031	A1	6/2007	Liang	
2008/0080979	A1	4/2008	Brassfield et al.	
2010/0040480	A1	2/2010	Webster et al.	
2010/0068068	A1	3/2010	Liang	
2011/0027102	A1 *	2/2011	Nakamata et al.	416/97 R
2011/0236221	A1	9/2011	Campbell	

FOREIGN PATENT DOCUMENTS

EP	1327747	A2	7/2003
EP	1775420	A2	4/2007
GB	2314126	A	12/1997

OTHER PUBLICATIONS

EP Search Report for Application No. 13 176 906.9 dated Nov. 18, 2013.

EP Examination Report for Application No. 13 176 906.9 dated Dec. 5, 2013.

* cited by examiner

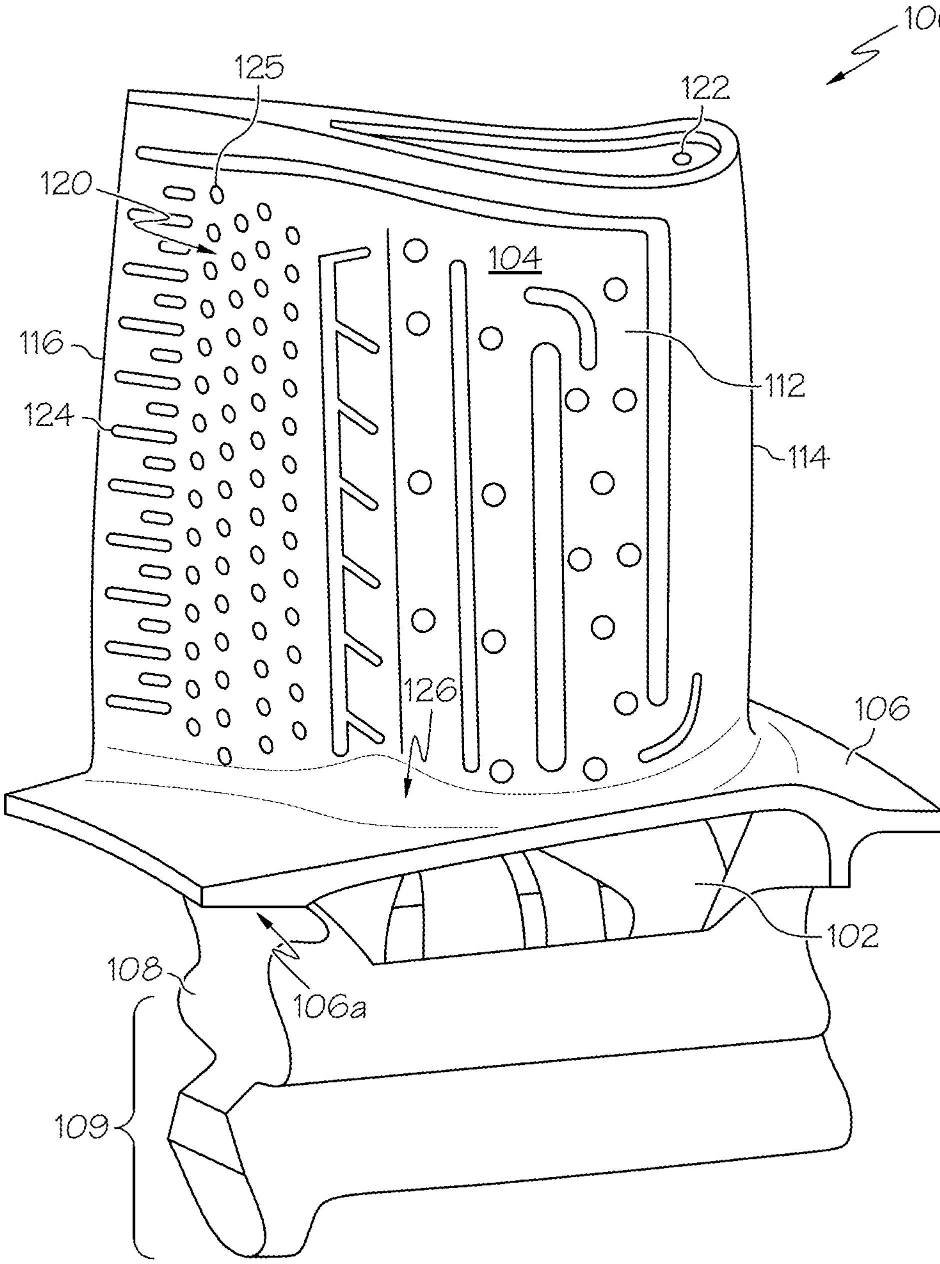


FIG. 1

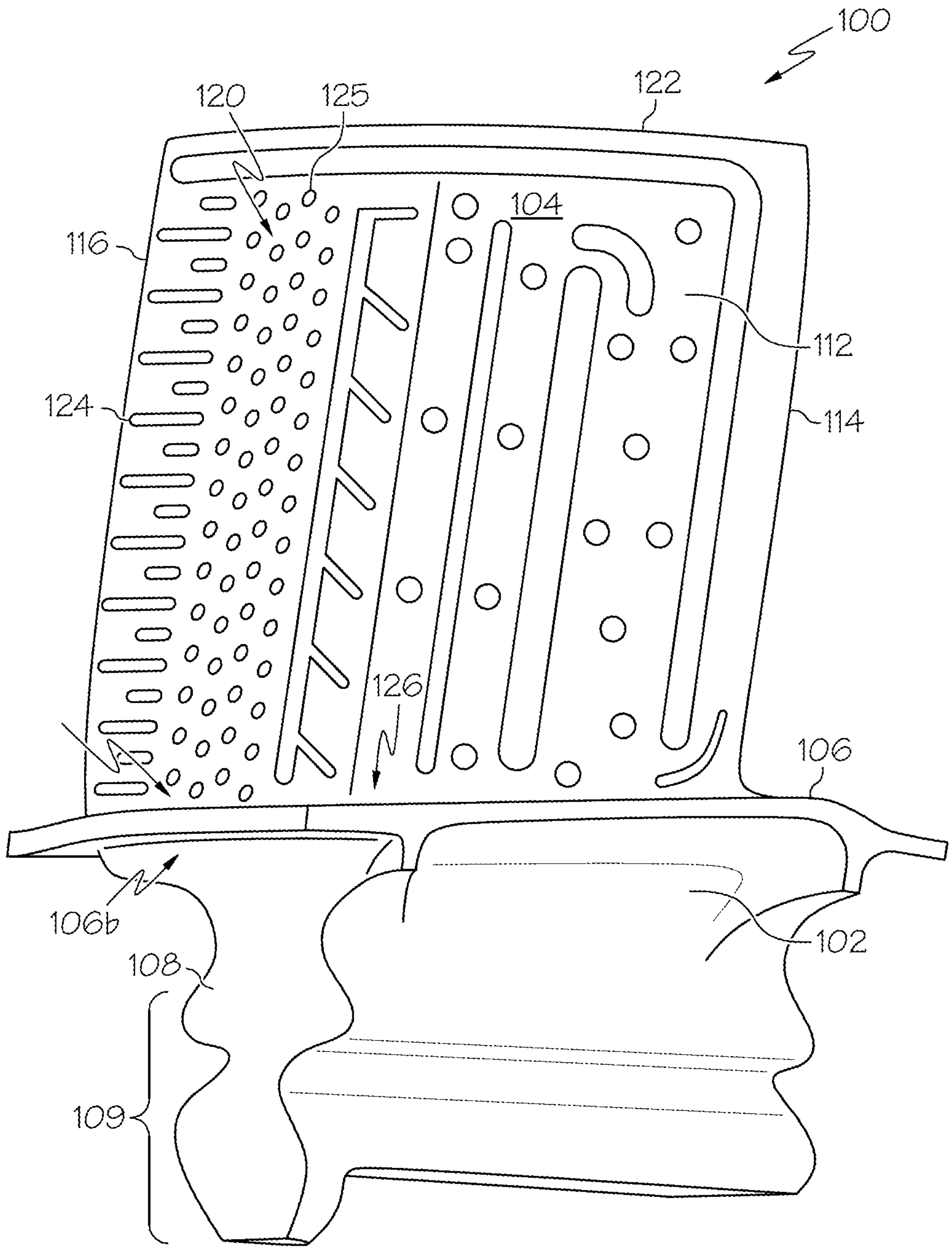


FIG. 2

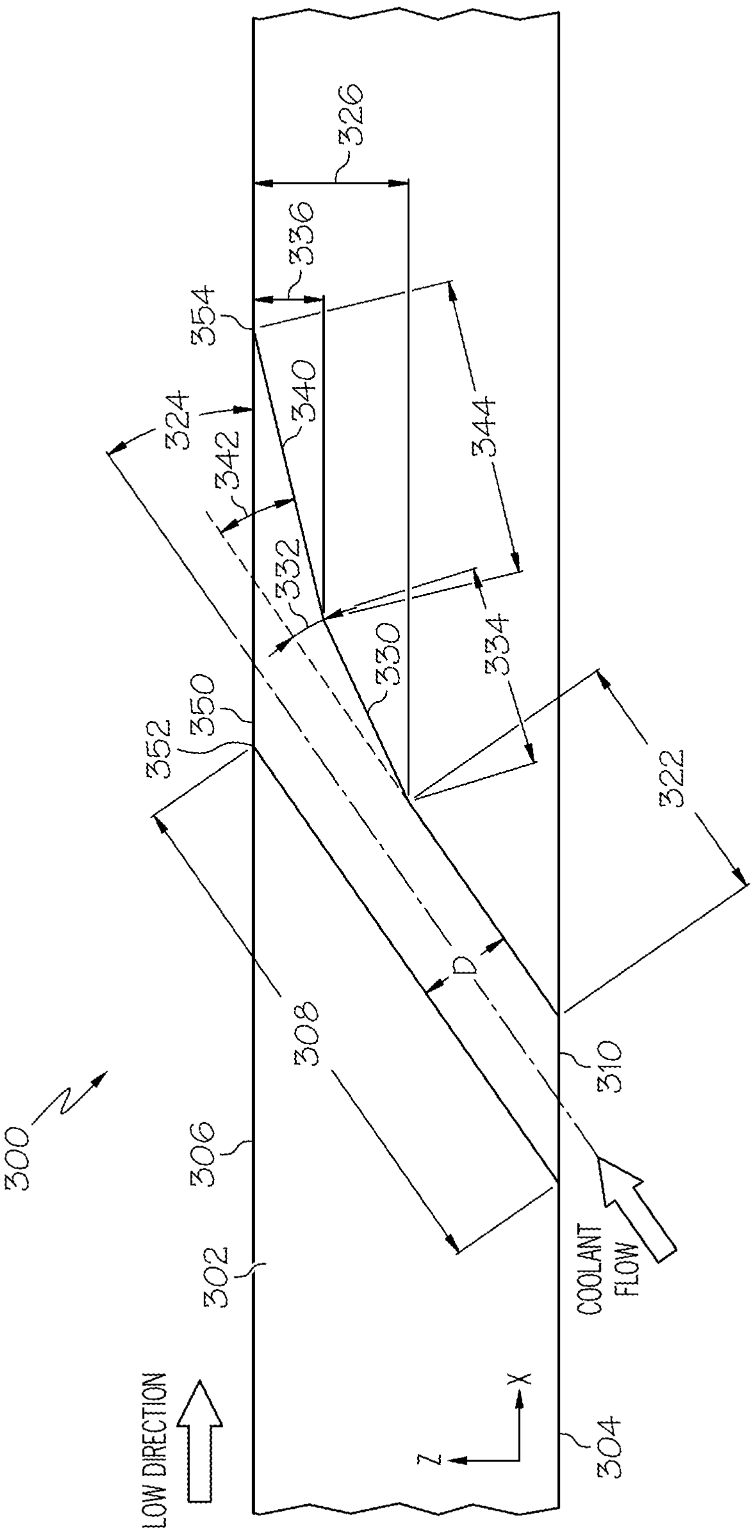

326
336
354
340
324
342
344
332
330
334
350
352
322
D
308
310
300
306
302
COOLANT FLOW
LOW DIRECTION
X
Z
304

FIG. 3

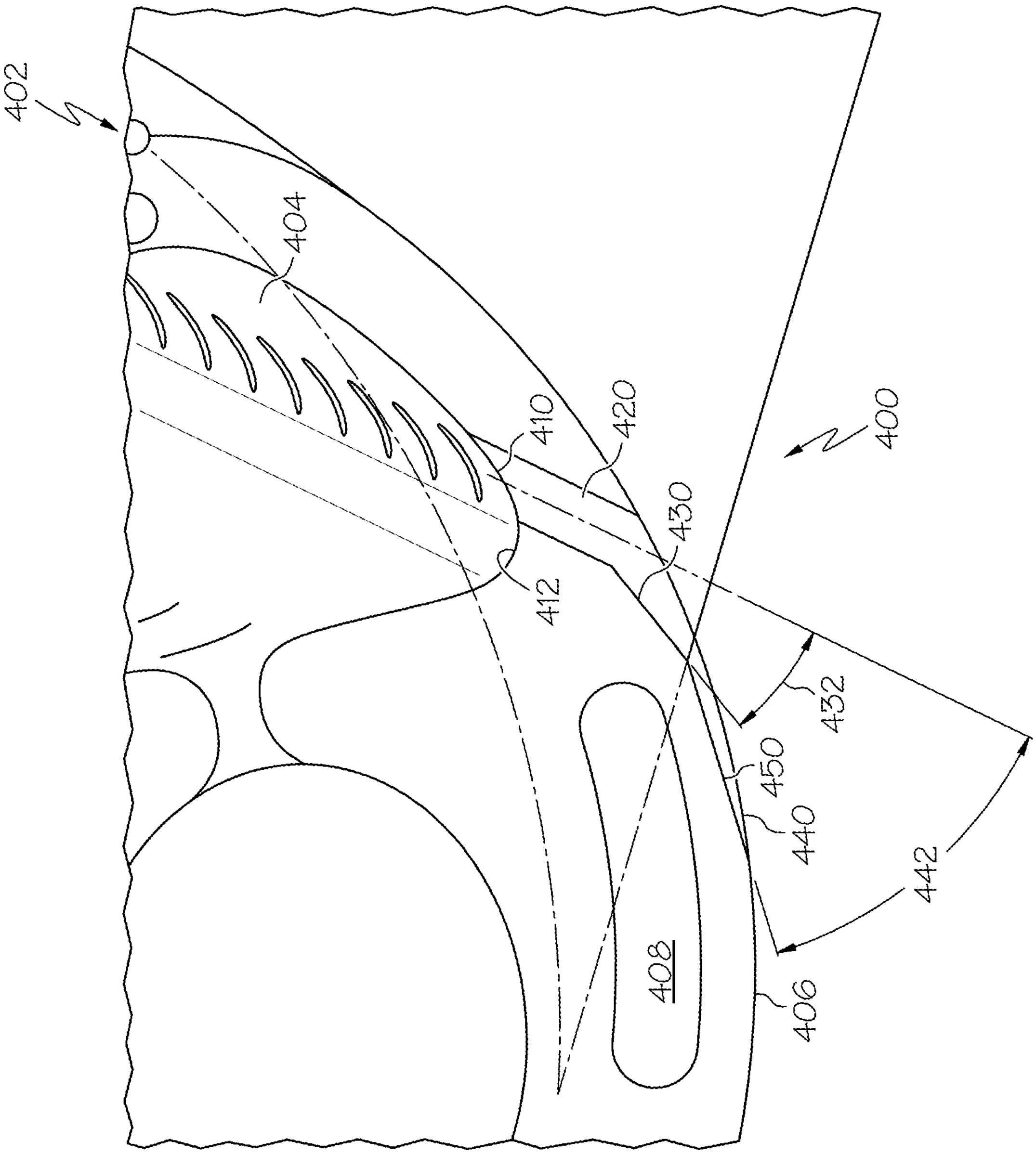


FIG. 4

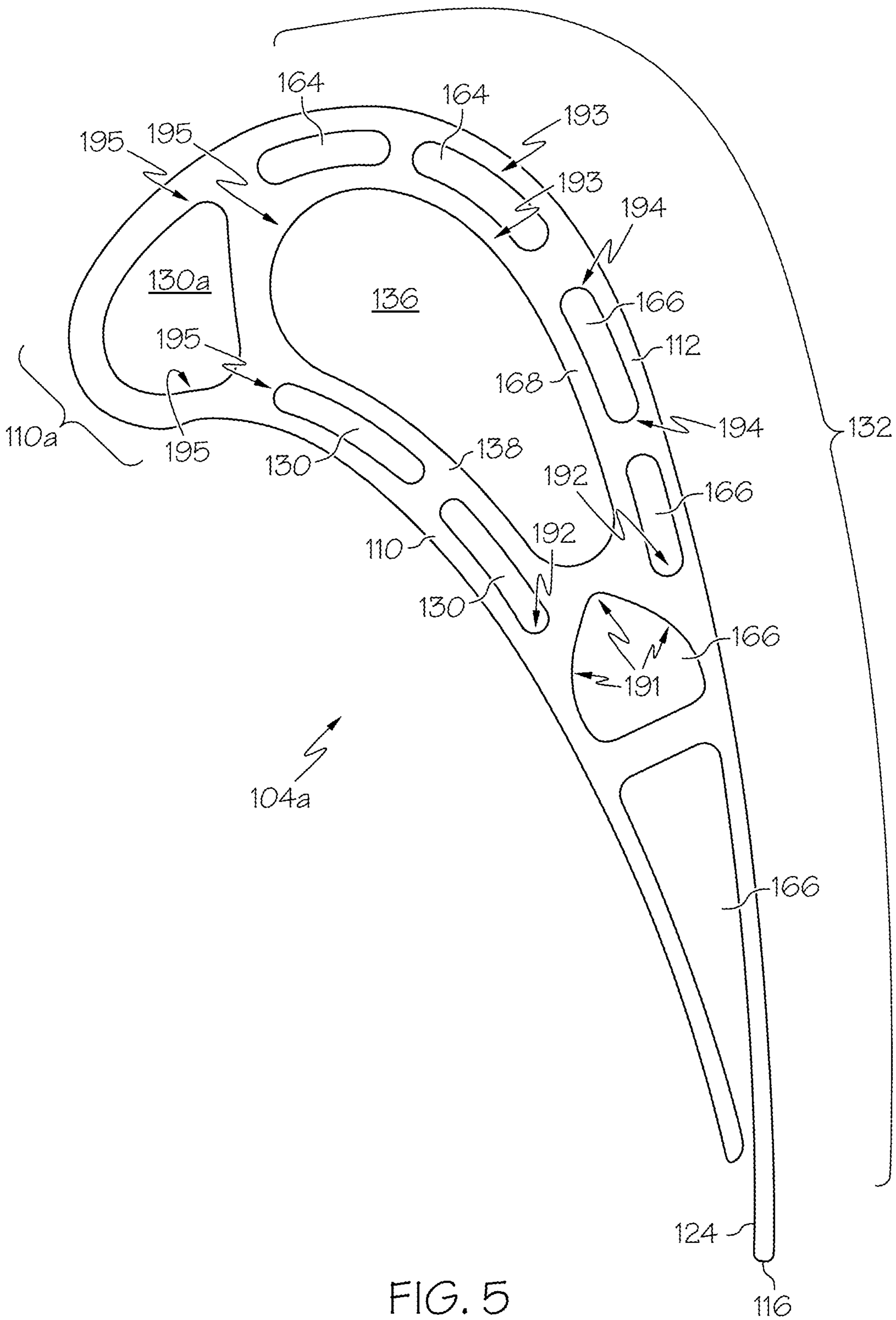

164
164
193
195
195
193
194
130a
136
166
195
112
168
194
132
110a
195
130
138
192
166
110
192
130
166
191
104a
166
124
116

FIG. 5

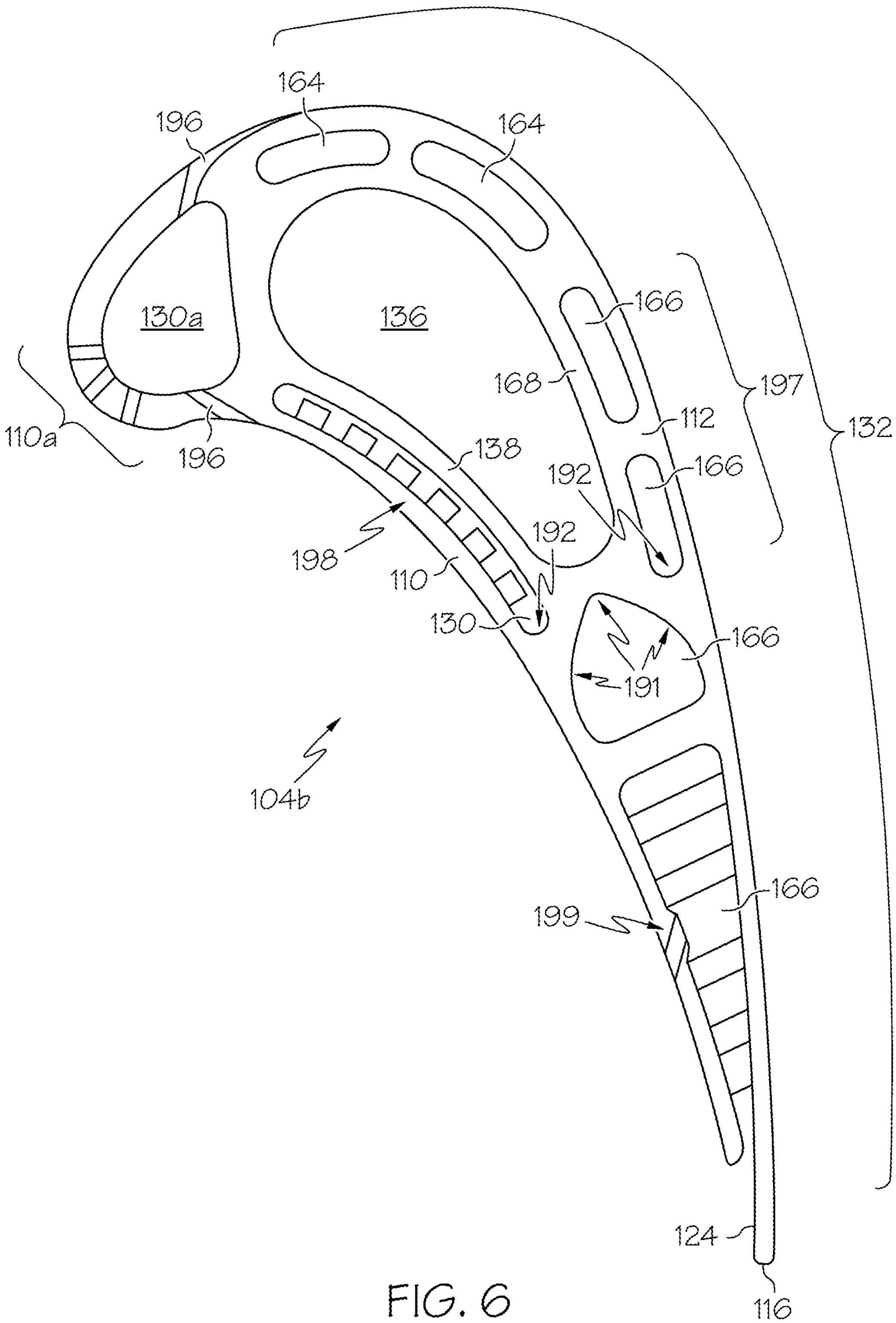

164
164
196
130a
136
166
168
197
112
132
110a
196
138
166
192
192
198
110
130
166
191
104b
166
199
124
116

FIG. 6

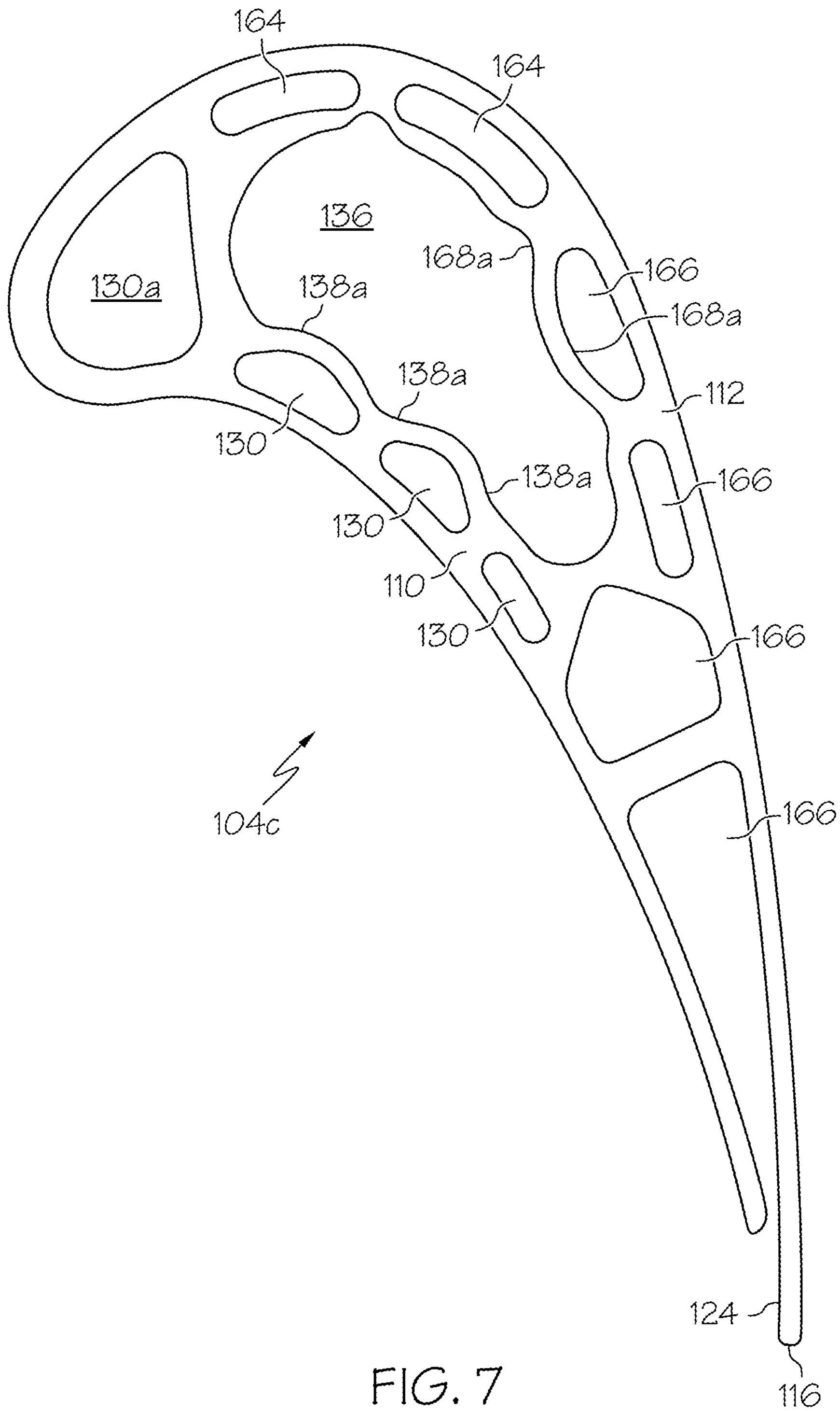

164
164
136
168a
166
130a
138a
168a
138a
112
130
166
138a
130
110
130
166
104c
166
124
116

FIG. 7

COOLED TURBINE AIRFOIL STRUCTURES

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

This invention was made with Government support under W911W6-08-02-0011 awarded by the US Army. The Government has certain rights in the invention.

TECHNICAL FIELD

The present invention generally relates to turbine engines, and more particularly relates to turbine engines with cooled airfoil structures.

BACKGROUND

Gas turbine engines, such as turbofan gas turbine engines, may be used to power various types of vehicles and systems, such as, for example, aircraft. Typically, these engines include turbine airfoils (or airfoils) that are impinged by high-energy compressed air that causes a turbine of the engine to rotate at a high speed. Consequently, the airfoils are subjected to high heat and stress loadings which, over time, may reduce their structural integrity.

Modern aircraft jet engines have employed internal cooling systems in the airfoils to maintain the airfoil temperatures within acceptable limits. Typically, the airfoils are air cooled using, for example, bleed air from a compressor section of the engine. The air may enter near the airfoil root, and then flow through a cooling circuit formed in the turbine airfoil. The cooling circuit typically consists of a series of connected cooling passages that form serpentine paths, which increase the cooling effectiveness by extending the length of the air flow path.

One exemplary cooling system is multi-walled and includes independent cooling circuits for the various surfaces of an airfoil, such as pressure and suction side surfaces, to thereby control specific heat load distributions thereon. The walls form intricate passages through which the cooling air flows to feed serpentine thin outer wall passages that incorporate pin fins, turbulators, turning vanes, and other structures therein. Although the cooling system operates adequately to cool most of the airfoil's pressure and suction side surfaces, it has been found that some portions of the airfoil may not be sufficiently cooled. Specifically, in some instances when these portions are exposed to extreme heat environments, they may oxidize, fatigue, and may become prematurely worn.

Hence, there is a need for an improved cooling system that is capable of cooling turbine airfoils in extreme heat environments without allowing the airfoil to fatigue or become prematurely worn. Additionally, it would be desirable for the system to be designed such that the airfoil may be manufactured relatively easily and inexpensively. Furthermore, other desirable features and characteristics of the present invention will become apparent from the subsequent detailed description and the appended claims, taken in conjunction with the accompanying drawings and this background of the invention.

BRIEF SUMMARY

In accordance with an exemplary embodiment, disclosed is an air-cooled turbine blade having an airfoil shape, including a convex suction side wall, a concave pressure side wall, the walls including an interior surface that defines an interior with

the blade, a suction side flow circuit formed within the blade interior, a pressure side flow circuit formed within the blade interior; and a trailing edge pin bank positioned aft of the suction side and pressure side flow circuits. The turbine blade includes a wishbone-shaped architecture at a transition point between the suction side flow circuit and the pressure side flow circuit and the trailing edge pin bank.

In accordance with another exemplary embodiment, disclosed is an air-cooled turbine blade having an airfoil shape that includes a convex suction side wall, a concave pressure side wall, the walls including an interior surface that defines an interior with the blade, a suction side flow circuit formed within the blade interior, a pressure side flow circuit formed within the blade interior, and a trailing edge pin bank positioned aft of the suction side and pressure side flow circuits. The pressure side flow circuit includes a plurality of pins positioned on an outer wall of the flow circuit extending towards, but not in contact with, an inner wall of the flow circuit.

In accordance with yet another exemplary embodiment, disclosed is an air-cooled turbine blade having an airfoil shape that includes a convex suction side wall, a concave pressure side wall, the walls including an interior surface that defines an interior with the blade, a suction side flow circuit formed within the blade interior, a pressure side flow circuit formed within the blade interior, a trailing edge pin bank positioned aft of the suction side and pressure side flow circuits, and a platform comprising a first external airfoil fillet on the suction side and a second external airfoil fillet on the pressure side. The external airfoil fillet on the suction side is at least 10% greater in size than the external airfoil fillet on the pressure side. The pressure side flow circuit comprises a plurality of pins positioned on an outer wall of the flow circuit extending towards, but not in contact with, an inner wall of the flow circuit. Further, the turbine blade comprises a wishbone-shaped architecture at a transition point between the suction side flow circuit and the pressure side flow circuit and the trailing edge pin bank.

This summary is provided to introduce a selection of concepts in a simplified form that are further described below in the detailed description. This summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used as an aid in determining the scope of the claimed subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

The present disclosure will hereinafter be described in conjunction with the following drawing figures, wherein like numerals denote like elements, and wherein:

FIG. **1** is a perspective suction (convex) side view of an engine turbine rotor blade that incorporates an exemplary airfoil of the blade;

FIG. **2** is another perspective suction side view of a turbine rotor blade of FIG. **1**;

FIG. **3** is a cross-sectional view of a cooling hole in accordance with an exemplary embodiment;

FIG. **4** is a cross-sectional view of a portion of a blade in accordance with an exemplary embodiment;

FIG. **5** is a cross-sectional view of a turbine airfoil in accordance with an embodiment;

FIG. **6** is another cross-sectional view of a turbine airfoil in accordance with an embodiment; and

FIG. **7** is yet another cross-sectional view of a turbine airfoil in accordance with an embodiment.

DETAILED DESCRIPTION

The following detailed description is merely exemplary in nature and is not intended to limit the invention or the application and uses of the invention. As used herein, the word "exemplary" means "serving as an example, instance, or illustration." Thus, any embodiment described herein as "exemplary" is not necessarily to be construed as preferred or advantageous over other embodiments. Furthermore, as used herein, numerical ordinals such as "first," "second," "third," etc., such as first, second, and third components, simply denote different singles of a plurality unless specifically defined by language in the appended claims. All of the embodiments and implementations of the stator airfoil assemblies and methods for the manufacture thereof described herein are exemplary embodiments provided to enable persons skilled in the art to make or use the invention and not to limit the scope of the invention, which is defined by the claims. Furthermore, there is no intention to be bound by any expressed or implied theory presented in the preceding technical field, background, brief summary, or the following detailed description.

Certain sections of gas turbine engines that are exposed to hot gasses, hereinafter referred to as "hot sections," require cooled turbine airfoil components when turbine inlet temperatures become high enough to cause distress in uncooled airfoil components. As turbine inlet temperatures continue to increase, more sophisticated cooling schemes are required to satisfy performance and cooling flow requirements. Multi-walled turbine airfoils utilize a thin outer wall to protect the thicker and cooler load-bearing inner walls to thus reduce the bulk metal temperature of the airfoil, which improves stress rupture capability. A typical multi-walled airfoil mid-span temperature distribution between the inner and outer walls results in hot outer walls and cooler inner walls, which in turn results in high thermo-mechanical stresses in the airfoil, due to the relative thermal expansions of the cooler inner walls and ribs with respect to the hotter outer walls. The combination of high temperatures and stresses results in very low thermo-mechanical fatigue (TMF) life, for example, on the order of hundreds or maybe thousands of cycles of life in prior art architectures. However, commercial engine applications typically require tens of thousands of cycles of TMF life. Thus, there is a need for an improved multi-walled turbine airfoil with improved TMF life. Embodiments of the present disclosure address at least this need.

Embodiments of the present disclosure provide a thermo-mechanical fatigue (TMF) resistant architecture to reduce thermo-mechanical stresses in multi-wall blades that result in low TMF life. FIGS. **1** and **2** illustrate an exemplary aircraft jet engine turbine rotor blade **100** that includes a shank **102**, an airfoil **104**, a platform **106**, and a root **108**. The platform **106** is configured to radially contain turbine airflow. The root **108** provides an area in which a firtree **109** is machined. The firtree **109** is used to attach the blade **100** to a turbine rotor disc (not illustrated). It will be appreciated that in other embodiments, any one of numerous other shapes suitable for attaching the blade **100** to the turbine disc may be alternatively machined therein. The airfoil **104** has two outer walls: a concave outer wall (not shown) and a convex outer wall **112**, each having outer surfaces that together define an airfoil shape. The airfoil shape includes a leading edge **114**, a trailing edge **116**, a pressure side (not shown) along the first outer wall, a suction side **120** along the second outer wall **112**, a blade tip **122**, one or more trailing edge slots **124**, pin fins **125**, and an external airfoil fillet **126**.

In one embodiment, as shown in FIGS. **1** and **2**, the external airfoil fillet **126** is locally increased in size along suction side **120** of the airfoil **104** at the platform **106** to reduce stress concentration from multi-wall cores. As such, the fillet **126** is greater in size along the suction side **120** than a corresponding fillet present on the pressure side. The fillet **126**, for example, may be 50%, 100%, 200% (or any percentage thereinbetween) greater in size along the suction size to reduce the concentration of stress on the multi-cored walls. The precise increase in size will be dependent on the configuration of the airfoil, and it is expected that one skilled in the art will be able to utilize finite element analysis methods to optimize the increase in size of the fillet **126** in accordance with a particular design.

In another embodiment, as further shown in FIG. **1**, an aft portion of the platform **106*a*** is tapered, i.e., decreased in width in the aft direction, for reduced stresses and higher temperature capability. Similarly, as shown in FIG. **2**, a fillet on the underside of the aft portion of the platform **106*b*** is increased in size, also for reduced stresses and higher temperature capability. As used herein, the filet **106*b*** is proportionally increased in size as compared to fillets of similar location known in the art. The fillet **106*b***, for example, may be 50%, 100%, 200% (or any percentage thereinbetween) greater in size. This configuration improves the platform life and avoids platform distress seen in the prior art. In alternative embodiments, the platform fillet **106*b*** may be a local addition to attenuate the local stress concentration in the platform similarly to employing localized fillet **126** on the external airfoil fillet.

To reduce metal fatigue in the leading edge impingement cavity, the leading edge impingement cavity pressure side and suction side film rows may be moved forward out of high stress fillets using multi-angle forward swept cooling holes to maintain optimal film cooling. These cooling holes utilize multiple angles to avoid breaking into the outer skin cores, and can be located forward of high stress fillet regions to provide film cooling. Greater detail regarding these cooling holes is provided in co-pending U.S. patent application Ser. No. 13/465,647, filed on 7 May 2012, the contents of which are herein incorporated by reference in their entirety, and is also provided with regard to FIGS. **3** and **4**, below.

FIG. **3** is a cross-sectional view of a cooling hole **300**, which may correspond to the cooling holes used in turbine airfoils, although cooling hole **300** may represent a cooling hole in any engine component. The cooling hole **300** extends through a wall **302** between an inner surface **304** and an outer surface **306** at a longitudinal length **308**. The inner surface **304** forms a portion of a cooling circuit to receive cooling flow, and the outer surface **306** is exposed to the mainstream hot gas flow. Generally, the cooing hole **300** includes an inlet **310**, a relatively straight metering portion **322**, a first exit portion **330**, a second exit portion **340**, and an outlet **350**. The inlet **310** may be any suitable shape, such as oval, and defined in the inner surface **304**. The metering portion **322** extends from the inlet **310** and may have a size, shape, and length to meter the appropriate amount of cooling air through the hole **300**. The metering portion **322** may be inclined relative to the outer surface **306** at any suitable angle **324** and extend to any suitable depth, e.g., from the inner surface **304** to a depth **326** from the outer surface **306**. In one exemplary embodiment, the metering portion **322** may be inclined relative to the inner surface **304** at an angle of 20°-35°, as examples.

The first exit portion **330** extends from the metering portion **322**. The first exit portion **330** may have any suitable shape, including the shapes described in greater detail below. The first exit portion **330** extends at an angle **332** relative to the metering portion **322** at a length **334**, e.g. from the depth **326** of the metering portion **322** to depth **336** relative to the outer surface **306**. The second exit portion **340** extends from the first exit portion **330**. The second exit portion **340** may have any suitable shape, including the shapes described in greater detail below. The second exit portion **340** extends at an angle **342** relative to the metering portion **322** at a length **344**, e.g., from the depth **336** to the outer surface **306**. Like the first and second exit portions **330**, **340**, the outlet **350** may have any suitable shape, including the shapes described in greater detail below. The outlet **350** may be considered to have a leading edge **352** and a trailing edge **354**, which generally refer to the orientation of the hole **300** relative to mainstream gas flow. As shown in FIG. **3**, the angle **342** of the second exit portion **340** is greater that the angle **332** of the first exit portion **330** such that the hole **300** may be considered to have a forward sweep configuration. Although the hole **300** has two, generally increasing angled portions (e.g., angles **332** and **342**), other exemplary embodiments may have additional exit portions with further increasing angles.

In some embodiments, increasing the angle of the second exit portion **340** relative to the first exit portion **330** enables the placement of cooling flow in areas that may have been previously unavailable for cooling. For example, FIG. **4** is a cross-sectional view of a cooling hole **400**, similar to the cooling hole **300** of FIG. **3**, incorporated into an airfoil **402**. As above, the cooing hole **400** includes an inlet **410**, a relatively straight metering portion **420**, a first exit portion **430**, a second exit portion **440**, and an outlet **450**. The inlet **410** may be any suitable shape, such as oval, and receives cooling air flow from cavity (or circuit portion) **404**. The metering portion **420** extends from the inlet **410** and may function to meter the appropriate amount of cooling air through the hole **400**. The first exit portion **430** extends from the metering portion **420** at a first angle **432**, and the second exit portion **440** extends from the first exit portion **430** at a second angle **442** relative to the metering portion **420**. As a result of the angles **432**, **442**, the cooling hole **400** is configured to provide cooling air to a location (e.g., location **406**) that is a relatively large distance from the cavity **404**, which may be an area that may otherwise be difficult to cool. For example, because of metering, air flow considerations, or source issues, it may be otherwise difficult to provide cooling air from a closer cavity (e.g., cavity **408**) to location **406**. Similarly, without angles **432**, **442**, it would be difficult to provide cooling air from cavity **404** to location **406**, e.g., cavity **408** may otherwise impede or prevent a direct cooling hole or a simple compound cooling hole from delivering cooling air flow directly to location **406**. Utilization of the multi-forward angle swept cooling hole **400** allows the inlet **410** to be moved away from the high stressed fillet **412**, which concentrates the thermal stresses due to thermal gradients between the cooler inner walls (FIG. **5** items **138** and **168**) and the hotter outer walls (FIG. **6** items **110** and **112**).

With reference to FIGS. **5** and **6** (which depict, in cross-section, exemplary airfoils **104***a*, **104***b*, respectively), a pressure side flow circuit **130** is defined, in part, by a pressure side wall **110** and an interior wall **138**. The interior wall **138** isolates the pressure side flow circuit **130** from the other flow circuits, as will be described below. Additionally, a suction side flow circuit **132** directs cooling air from the root **108** (not shown) along the suction side wall **112** and out one or more of the trailing edge slots **124** or cooling holes (not shown) formed on the pressure side wall **110** and on the blade tip. The suction side flow circuit is divided into a suction side forward flow circuit **164** and a suction side aft flow circuit **166**. The suction side forward flow circuit **164** is defined by the suction side wall **112** and an interior wall **168**. The suction side aft flow circuit **166** is also defined by the suction side wall **112** and the interior wall **168**, but is positioned more aft along the airfoil. Further, the center flow circuit **136** takes air from the root **108** (not shown) and cools internal walls that also define portions of the other flow circuits.

In one embodiment, as further shown in FIGS. **5** and **6**, the incorporation of an angled or "wishbone" architecture **191** is provided at a transition region of outer walls **110**, **112** to the trailing edge **116**. This angled or wishbone architecture **191** provides a compliance transition zone between the hot outer wall stress loop and the cooler inner wall stress loops. In combination with this wishbone architecture, embodiments of the present disclosure may include multi-radius compound fillets **192** at a transition from the outer walls **110**, **112** to the wishbone architecture **191** in order to improve load path and reduce stress concentrations.

As illustrated particularly in FIG. **5**, in a further aspect of the present disclosure, the thickness of walls **112**, **168** (or **110**, **138**) may be optimized to a ratio between thin, hotter outer walls with thicker, cooler inner walls that balances compliance and stresses around the airfoil. Arrows **193** illustrate the difference in thickness of walls **112**, **168** (or **110**, **138**) at a particular area along the airfoil. For example, in one embodiment, the thickness ratio between walls **112** and **168** (or **110**, **138**) may be 1:1.2, 1:1.5, 1:2.0, 1:3.0, or any ratio thereinbetween. Walls **112** and **168** (or **110**, **138**) may further utilize full or multi-radius compound fillets **194** to drive peak stress concentrations towards inner walls where the temperature is lower, thus increasing TMF life. For example, it will be appreciated that a 25° F. temperature reduction can equate to a factor of 2 in TMF life. As further illustrated in FIG. **5**, the leading edge portion **130***a* of the pressure side flow circuit **130** may include stress reduction features **195** in the manner of one or more of: a tapered cavity, multi-radius compound fillets, and/or leading edge wall **110***a* thickness and curvature optimization (for compliance control around leading edge stress loop), in order to reduce stress concentration at the leading edge portion **130***a*.

Reference is now made to FIG. **6**, which discloses additional features of the airfoil **100** in accordance with certain embodiments. In one aspect, compliance enhancement between walls **110**, **138** (or **112**, **168**) may be provided via a series of pins, indicated generally by reference numeral **198**, from the hotter outer wall **110** (or **112**) protruding towards the cooler inner wall **138** (or **168**) to allow for heat conduction from outer wall **110** (or **112**) and stress reduction by elimination of shear and tensile stresses at pin **198** to inner wall **138** (or **168**) interfaces.

In a further aspect, as also shown particularly in FIG. **6**, the number, location, and thicknesses of the rib fillets (several of which are identified by bracket **197** in FIG. **6**) may be optimized to balance stresses in the rib fillets with thermal conduction from hotter outer walls **110**, **112** to the cooler inner walls **138**, **168**. In yet a further aspect, the pressure side aft film cooling row utilizes locally thicker wall (indicated at **199**) to reduce background stress and to improve film cooling hole metering and diffusion for enhanced film cooling. Still further, reference numeral **196** identifies exemplary multi-angle forward swept cooling holes as described in greater detail above with regard to FIGS. **3** and **4**.

FIG. **7** depicts an alternate embodiment of the present disclosure, illustrated by an airfoil **104***c*. In this embodiment, curved walls **138***a*, **168***a* provide compliance and stress balancing between cooler inner walls and hotter outer walls. For example, curvature may be provided that extends the length of the walls **138***a*, **168***a* by 10%, 20%, or 30% (or any percentage thereinbetween) as compared to the straight interior wall (**138**, **168**) embodiments shown with regard to FIGS. **5** and **6**. Those skilled in the art may utilize finite element analysis methods for transient thermal and stress analyses to define curvature, relative thicknesses, and fillet parameters to optimize the relative compliance and resulting stress field to improve TMF life for the component. The reference numerals illustrated in FIG. **7**, but not specifically mentioned with regard thereto, illustrate the same components of the airfoil as described above with regard to FIGS. **5** and **6**.

Regarding the design and manufacture of the presently disclosed cooled turbine airfoils, the embodiments may be incorporated into multi-walled airfoils using casting technologies known to those skilled in the art. Stress and thermal optimizations may be performed by standard conjugate aero-thermal analysis followed by stress analysis with commercially available software such as ANSYS. Machining features are incorporated by standard techniques, including machining, grinding, and electro-discharge machining.

While at least one exemplary embodiment has been presented in the foregoing detailed description of the invention, it should be appreciated that a vast number of variations exist. It should also be appreciated that the exemplary embodiment or exemplary embodiments are only examples, and are not intended to limit the scope, applicability, or configuration of the invention in any way. Rather, the foregoing detailed description will provide those skilled in the art with a convenient road map for implementing an exemplary embodiment of the invention. Various changes may be made in the function and arrangement of elements described in an exemplary embodiment without departing from the scope of the invention as set forth in the appended claims.

What is claimed is:

1. An air-cooled turbine blade having an airfoil shape, comprising:

a multi-walled convex suction side wall comprising a convex-side outer wall and a convex-side inner wall, wherein a space between the convex-side outer wall and the convex-side inner wall defines a convex-side cooling air passage;

a multi-walled concave pressure side wall comprising a concave-side outer wall and a concave-side inner wall, wherein a space between the concave-side outer wall and the concave-side inner wall defines a concave-side cooling air passage, each of the convex-side and concave side inner walls including an interior surface that defines an interior with the blade;

a suction side flow circuit formed within the convex-side cooling air passage;

a pressure side flow circuit formed within the concave-side cooling air passage; and

a plurality of pins at a trailing edge of the blade and positioned aft of the suction side and pressure side flow circuits,

wherein the turbine blade comprises, in a mid-section extending from the suction side flow circuit and the pressure side flow circuit to the plurality of pins at the trailing edge, a generally Y-shaped cross-section defined with a first end of the Y-shape extending from the suction side flow circuit to the plurality of pins and a second end of the Y-shape extending from the pressure side flow circuit to the plurality of pins, an open space being present between the first and second ends of the Y-shape in the mid-section, and wherein the pressure side flow circuit comprises a plurality of pins positioned on the concave side outer wall of the pressure side flow circuit extending towards, but not in contact with, the concave side inner wall of the pressure side flow circuit.

2. The turbine blade of claim **1**, further comprising a variable wall thickness between inner and outer walls of one or both of the suction side flow circuit and the pressure side flow circuit.

3. The turbine blade of claim **1**, comprising a plurality of multi-angle forward swept cooling holes.

4. The turbine blade of claim **1**, further comprising a platform comprising a first external airfoil fillet on the suction side and a second external airfoil fillet on the pressure side, wherein the external airfoil fillet on the suction side is at least 10% greater in size than the external airfoil fillet on the pressure side.

5. The turbine blade of claim **4**, wherein the platform is tapered at an aft end thereof.

* * * * *